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Application of BATEMAN ET AL.)

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 Filed: November 29, 2001) Examiner: N/A
 Atty Docket: DEH009

#5

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For: MASS SPECTROMETERS AND METHODS OF MASS
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Respectfully submitted,

 Everett G. Diederiks, Jr.
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 Registration Number: 33,323

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Ion Tunnel

Background and Prior Art

The use of rf only multipoles for transport, focussing and trapping of ions as well as conversion of discontinuous ion beams to continuous ones when used in higher pressure vacuum stages is well established and subject of several patents. A less well known rf device for collimating or trapping ions uses a stack of ring electrodes and was first developed to trap ions for the study of ion-molecule reactions or laser interactions with ions. A later development of the ring electrodes employs a stack with decreasing internal diameter to collimate, concentrate and transport ions through a high-pressure vacuum stage.

The first ring electrode device was developed in 1969 by Teloy and Bahr¹ to study thermal rate coefficients of ion-molecule interactions. Further enhancements to the approach are summarised in the review paper by Gerlich². The ring electrode device is made from a stack of metal plates or rings along an axis perpendicular to the central apertures and with fixed spacing. An rf voltage is then applied with 180° phase shift on adjacent plates which generates an effective potential along the axis which has a broad minimum in the radial direction but increases rapidly (exponentially) in the proximity of the electrodes. The field acts to contain ions to the central, low potential, region of the device. In the presence of a sufficient buffer gas in the assembly, ion kinetic and internal energy can be quenched essentially to that of the buffer gas. Consequently, in a typical experiment ions are injected and trapped in the ring electrodes where they undergo collisions with the buffer gas and/or a reagent gas. After a certain reaction time an extraction field is applied and the ions mass analysed and detected. This process is repeated for various trapping times to obtain a reaction rate coefficient.

A more recent manifestation of the ring electrode device has been pioneered by Smith and co-workers at Battelle³⁻⁷ to efficiently transport and focus ions in the relatively high pressure (1-10 Torr) vacuum stages of mass spectrometers operating with API sources. This device uses a stack of ring electrodes with continually decreasing aperture size to provide a large acceptance angle followed by focussing/collimation of the ion beam to a small diameter suitable for passage through a differential aperture into the next vacuum stage of the instrument. In this design, the rf is applied in the same manner as above to adjacent plates, but additionally a dc voltage gradient is provided along the axis of the 'tunnel' to force the ions in the direction of the smaller apertures.

In the Smith group's latest design of ion funnel⁷ a region of plates with constant aperture diameter has been added to the entrance of the ion funnel to reduce the gas dynamic effects upon ion confinement, to improve conductance for pumping, reduces gas load downstream and provides an extended ion residence time for enhanced desolvation.

In a recent publication by Smith and co-workers⁸ the ring electrode device is considered with constant internal diameter apertures with regard to trapping properties

compared to standard multipole assemblies. This paper deals only theoretically with the trapping properties of these devices.

A recent patent application⁹ deals with the use of a tapered ring electrode device with changing aperture shape to modify an ion beam shape prior to entry into an oa-ToF mass analyser. This device is reported to improve resolution in the analyser through reduction of the beam dimension in the time-of-flight direction. In addition, use of the device for ion fragmentation is also reported.

Present Design and Application

We have built a ring stack device with constant diameter apertures for use in the millibar vacuum region of the Quattro Ultima currently occupied by hexapole 1. This 'ion tunnel' directly replaces hexapole 1 and is used to guide/collimate/focus ions from the source block to the vacuum stage containing the second hexapole.

At present the tunnel uses plates of 5mm internal diameter spaced by 1mm and overall is around 125mm in length. The rf is supplied by a standard generator operating at 750 kHz with peak-to-peak voltages in the range of 0 to 350V. No dc voltage gradient is currently applied along the axis of the device however the facility to float assembly to a fixed voltage is available.

This ion tunnel appears to be at least as efficient as the standard hexapole for transmission of ions. Improvements in transmission, particularly at low mass have been realised through use of a source block with the extraction 'cone' replaced by a tunnel, possibly as a result of collimation of the gas/ion stream closer to the axis of the ion tunnel.

Further embodiment:

Continuous ion tunnel between different pressure regions with one or more lens plates forming a differential pumping aperture to improve ion transmission.

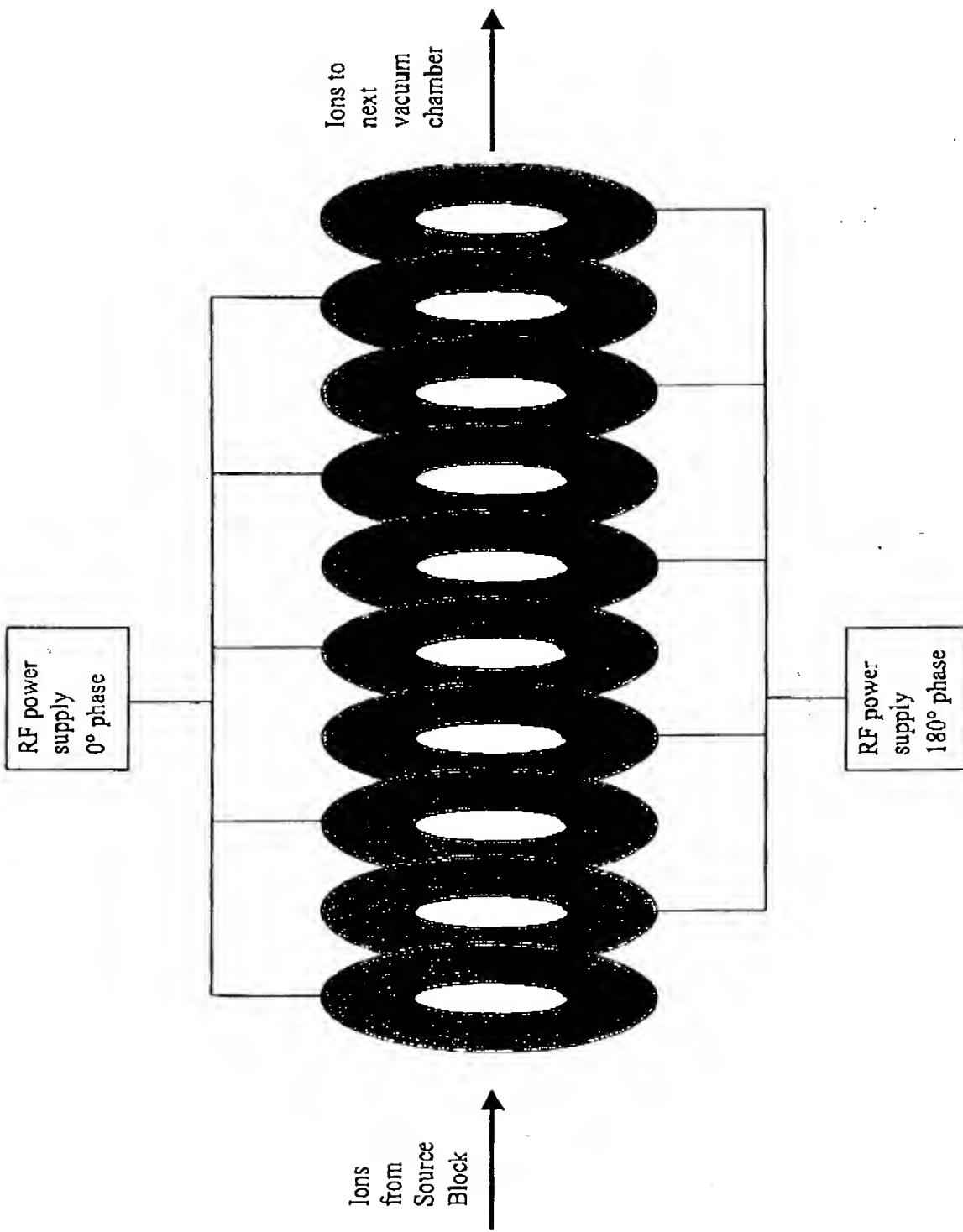
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- 2) Gerlich D, in State Selected and State to State Ion Molecule Reaction Dynamics, Part 1: Experiment. Eds CY Ng and M Baer, Advances in Chemical Physics Series, Vol. LXXXII, 1992. Wiley. Pages 93-99.
- 3) Patent US6107628, 'Method and Apparatus for Ion and Charged Particle Focusing', Smith RD, Tang K and Anderson GA, 1997.
- 4) Shaffer SA, Teng K, Anderson GA, Prior DC, Udseth HR and Smith RD, Rapid Commun. Mass Spectrom, 11 (1997) 1813-1817
- 5) Shaffer SA, Prior DC, Anderson GA, Udseth HR and Smith RD, Anal. Chem., 70 (1998) 4111-4119
- 6) Shaffer, SA, Tolmachev A, Prior DC, Anderson GA, Udseth HR and Smith RD, Anal. Chem., 71 (1999) 2957-2964
- 7) Kim T, Tolmachev AV, Harkewicz R, Prior DC, Anderson GA, Udseth HR, Smith RD, Bailey TH, Rakov S and Futrell JH, Anal. Chem., 72 (2000) 2247-2255
- 8) Tolmachev AV, Udseth HR and Smith RD, Anal. Chem., 72 (2000) 970-978
- 9) Jolliffe C and Thomson B, Patent application 'Mass Spectrometer with Tapered Ion Guide' 1998 (internal ref. No. 12804)

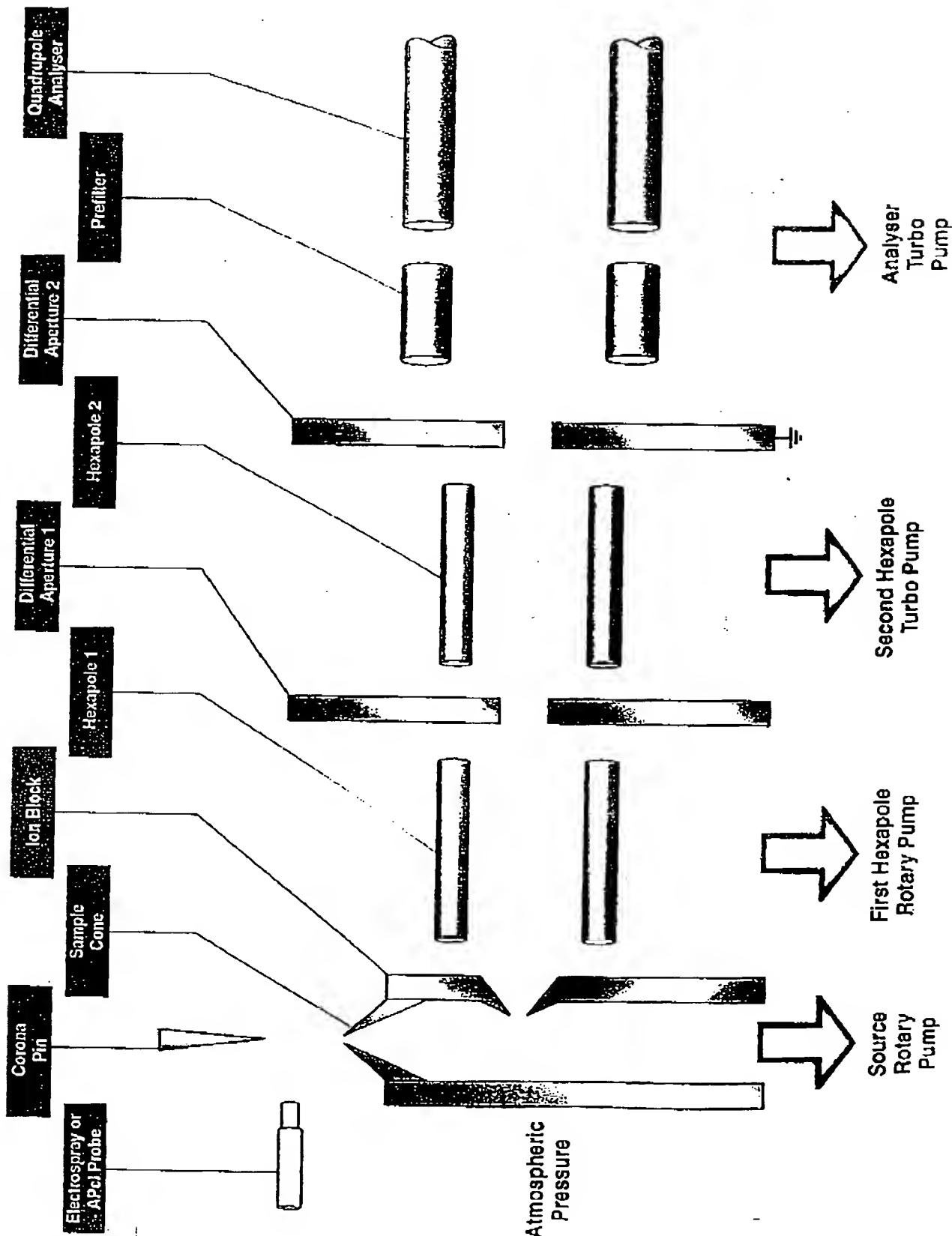
- (G) An illustrative schematic of the electrodes and supplies for the RF-only ion tunnel
- (H) An illustrative schematic of one of our existing arrangements with an atmospheric pressure ion source, where we use two RF-only hexapoles to transport ions through regions of relatively high pressure – where $(\text{pressure} \times \text{path length}) > 0.01 \text{ mbar}\cdot\text{cm}$.
- (I) An illustrative schematic of a similar arrangement where the first of the two RF-only hexapole lenses is replaced by an RF-only ion tunnel to transport ions through a region of relatively high pressure – where $(\text{pressure} \times \text{path length}) > 0.01 \text{ mbar}\cdot\text{cm}$.
- (J) An illustrative schematic of a similar arrangement where both the RF-only hexapole lenses are replaced by two RF-only ion tunnels to transport ions through regions of relatively high pressure – where $(\text{pressure} \times \text{path length}) > 0.01 \text{ mbar}\cdot\text{cm}$.
- (K) Manufacturing drawing of the Ion Stack Assembly actually used in our prototype ion tunnel design.

Please note that these sketches illustrate schemes for transporting ions from an atmospheric pressure ion source through to a quadrupole mass filter. The device could be used to transport ions from a variety of different ion sources, including pulsed ion sources such as matrix assisted laser desorption ionisation (MALDI), and into a variety of different mass analysers, including time-of-flight mass spectrometers.

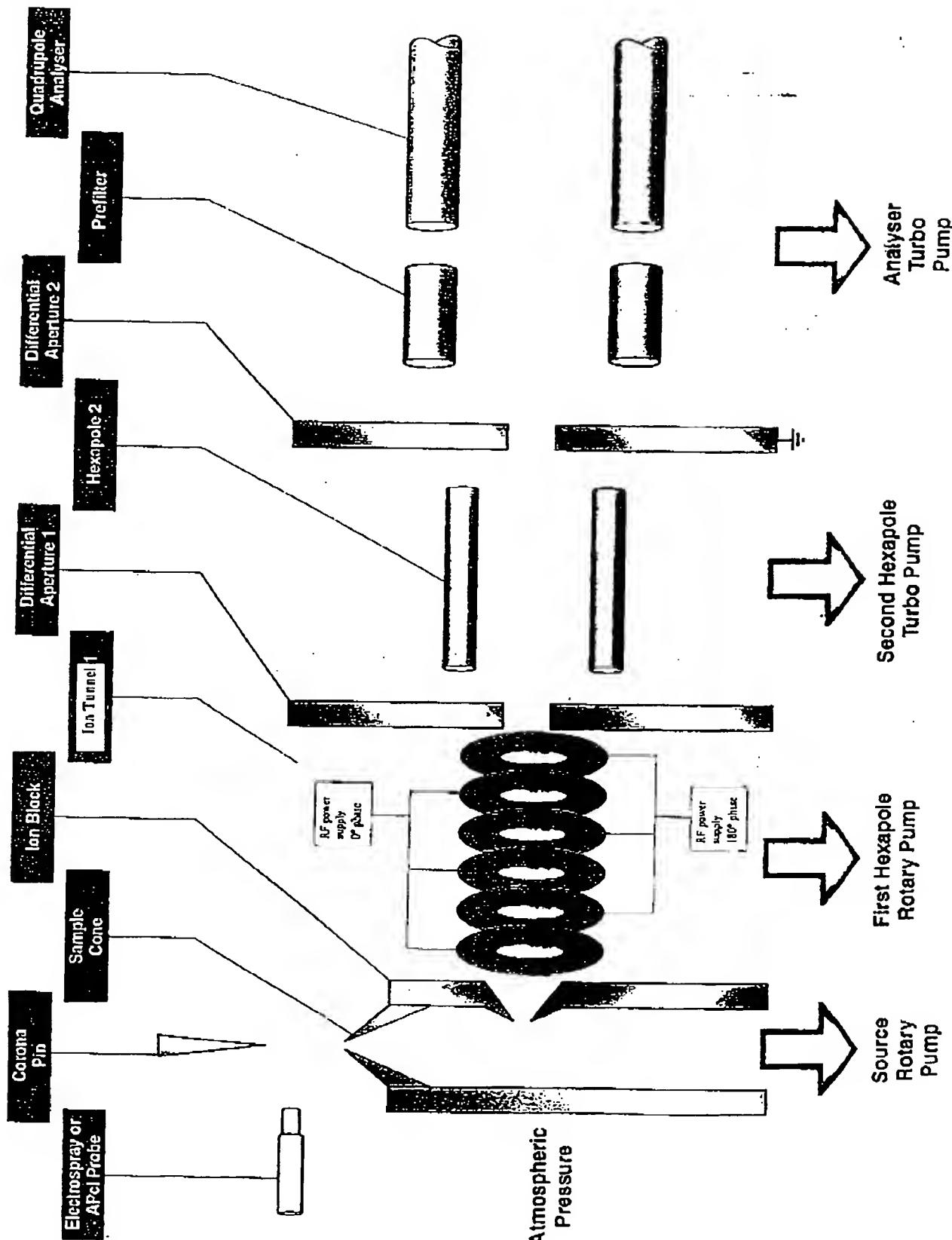
Ion Tunnel Schematic



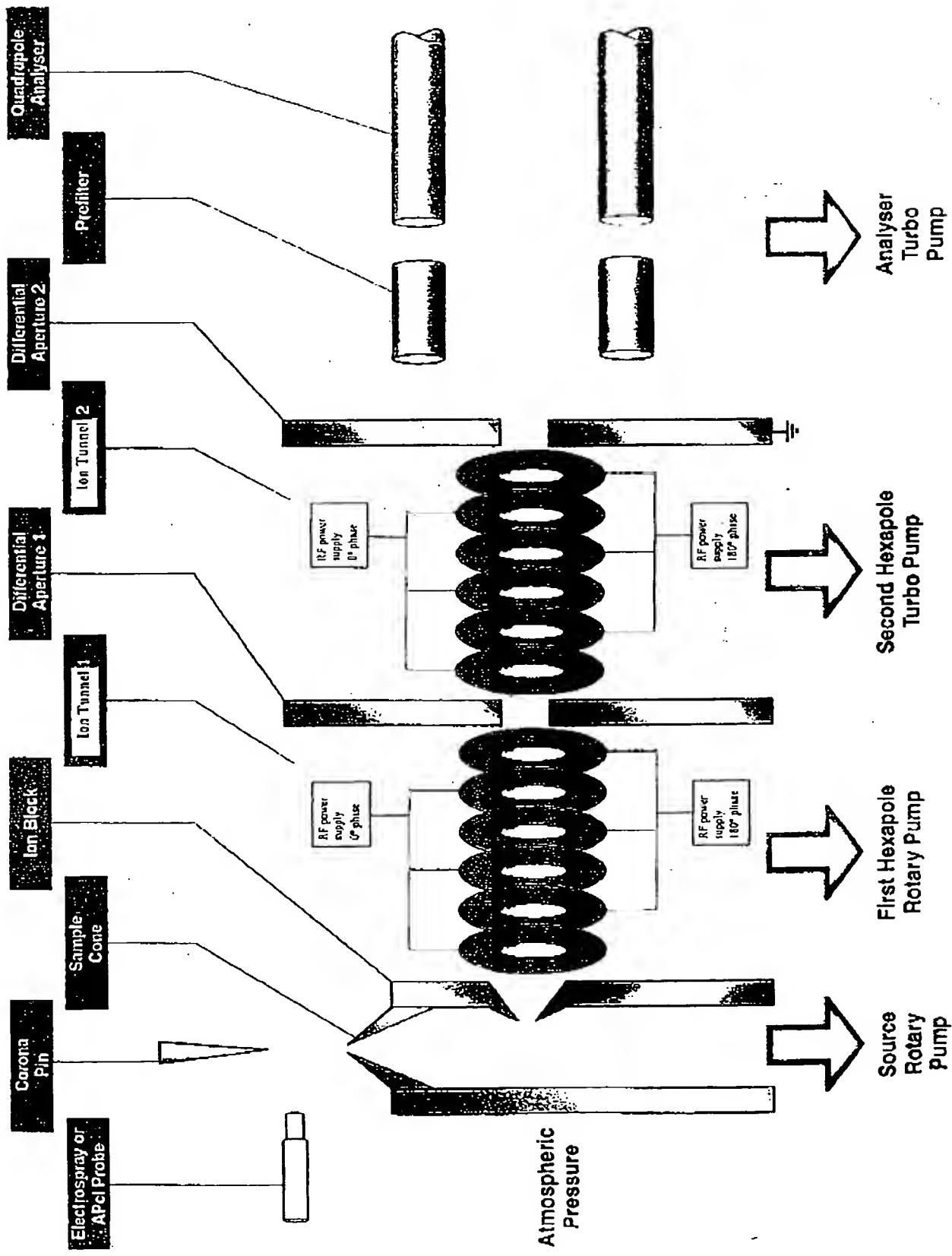
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